HOLOGRAPHIC NONDESTRUCTIVE TESTING OF PIPES

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THESIS

HOLOGRAPHIC NONDESTRUCTIVE TESTING OF PIPES

by

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Additional specimens with internal grooves, which simulate warheads, were tested to determine if fragmentation patterns could be predicted by nondestructive means using holographic techniques. The method of holographic interferometry shows great promise for immediate application for warhead development.

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Holographic Nondestructive Testing of Pipes

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Submitted in partial fulfillment of the
requirements for the degree of

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Additional specimens with internal grooves, which simulate warheads, were tested to determine if fragmentation patterns could be predicted by nondestructive means using holographic techniques. The method of holographic interferometry shows great promise for immediate application for warhead development.

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I. INTRODUCTION

A. BACKGROUND

A great deal has been written about the ability to use holographic methods for nondestructive testing, but very little qualitative study has been done in this area. The technique of holographic interferometry was first reported by Powell and Stetson in 1965 [1]. The ability to use this method to detect flaws in pipes was reported in 1971 [2]. The great advantage of holographic interferometry relative to classical interferometry is that the subject need not be an optically polished flat surface. Diffusely reflecting, three-dimensional objects with nonplanar surfaces can be studied.

Current techniques for the testing of pipes and piping systems include hydrostatic, ultrasonic, radiographic, dye penetrant, and magnetic particle testing. Radiographic testing is particularly time consuming and hazardous. The question was raised as to the practicality of using holographic testing to supplement or replace some of the current nondestructive testing techniques.

B. THESIS OBJECTIVE

The objective of this thesis was to determine the practicality of using holographic interferometry for the nondestructive testing of pipes. A secondary objective was to attempt to predict the deflections measured by holographic techniques using finite element methods.

II. EXPERIMENTAL METHODS

A. GENERAL

A hologram is formed when two wavefronts of beams of coherent light are used to expose a photographic plate. The object beam is reflected from the object of interest onto the photographic plate. The reference beam is shined directly onto the photographic plate. Where the two beams of light overlap an interference pattern is formed. Nodes of constructive interference and anti-nodes of destructive interference are formed. If all of the components in the optical path are stable, the interference pattern will be stationary and will thus expose the photographic plate in a series of light and dark bands. Due to the close spacing of the nodes in the interference pattern, a film with a very fine resolution capability must be used. If a helium-neon laser is used as the light source, the film must have a resolution capability of greater than 1200 lines per millimeter [4].

After the plate has been exposed, it is developed and dried. A hologram is then reconstructed by illuminating the plate with a beam similar to the original reference beam. When one observes the reconstruction by looking through the back of the plate toward the original scene, the reconstruction will appear identical to the original scene.

B. STATIC DOUBLE-EXPOSURE INTERFEROMETRIC HOLOGRAPHY

The process of making a double-exposure hologram is similar to the procedure described above except that two exposures

and hence two holograms of the object are recorded on the same photographic plate prior to processing. When the hologram is reconstructed, two images of the object will be formed. If the surface of the object was displaced slightly between the two exposures, the two reconstructed images which exist at approximately the same location in space will interfere with each other. A set of bright and dark fringes will be produced on the reconstructed image. Each fringe represents the loci of points of constant optical path change. Successive fringes represent a displacement of approximately one-half of the wave length of the light source used in the construction process.

This method has several advantages when used for nondestructive testing. The holographic plate can be used as permanent record of the test or the reconstruction can be photographed and used as a permanent record. Also, double-exposure holography usually produces the clearest fringe patterns compared to the real-time method. It is less susceptible to unwanted fringes caused by external influences, such as temperature.

C. REAL-TIME INTERFEROMETRIC HOLOGRAPHY

The real-time method is similar to the double-exposure method except that only a single exposure of the photographic plate is made. The plate is developed and returned to exactly the same position occupied prior to removal for developing. An alternative procedure is to develop the plate

in place. The wavefronts from the reconstructed hologram coincide with wavefronts originating at the object from which it was constructed. Any subsequent motion of the object results in the formation of interference fringes which can be viewed in real-time.

The major advantage of real-time holography is that it allows varying of the excitation of the object to obtain the desired fringe distribution without constructing a new hologram each time. For nondestructive testing purposes the holographic plate itself has no value as a permanent record of the test. The superimposed images can, however, be photographed to provide a record.

D. METHODS OF EXCITATION

There are many different possible methods of specimen excitation. The major requirement for choosing a method is that it must apply a mild stress to the surface of the object so that the surface will be displaced by a small amount. If the surface is displaced too much, there may be too many interference fringes to distinguish one from another or the interference pattern may disappear altogether. Possible methods of excitation include acoustic vibration, thermal excitation, pressurization, and mechanical force.

Successful inspection of a specimen requires the application of a stress in a manner such that the defect or parameter of interest will cause a distortion of an otherwise regular and predictable fringe pattern. Therefore, the

choice of the excitation method for any particular test situation is critical. The excitation must not cause a false indication of a flaw. Unwanted fringes may be formed if the excitation causes a rotation or translation of the specimen. To prevent this, the support of the object also must be planned carefully.

Acoustic stressing has been used in the testing of large surfaces which are deformed by moderate frequency plate wave propagation, but this method apparently does not have application in the testing of small pipes.

Thermal stressing methods are potentially useful but have several practical drawbacks. The major difficulty is the inability to achieve a uniform thermal stress pattern without elaborate equipment. If the fringes are shifting during exposure, the hologram will be blurred or fringes will not show at all. Several unsuccessful attempts were made to detect flaws in pipes using real-time holography by heating either the interior or exterior of the pipe with a heat gun. The interference patterns formed were interesting, but generally shifted too fast to allow an accurate interpretation.

Pressure stressing is the most effective means of testing hollow components. If the component is a closed system, either pressure or vacuum can be applied internally. Even open-ended components can be tested by means of a specially designed air bag or balloon inserted into the object. Pressure stressing is the most effective method of testing pipes. The only real problems are the determination of pressure required

to detect a given flaw and the correct support of the pipe section under test.

Mechanical stressing methods include a large number of possible testing techniques. Mechanical shakers can be used for component vibration analysis. A small bending movement can be applied to many components to provide a suitable stress. These methods do not generally apply to the testing of pipes.

III. EXPERIMENTAL PROCEDURE

A. SYSTEM DESCRIPTION

1. The Holographic System

All of the optical components of the holographic system were mounted on a vibration isolation table as shown in Figure 1. The table has a honeycomb stainless steel top which weighs approximately 1000 pounds. The top is drilled and tapped with ¼ - 20 mounting holes on one-inch centers. The table top is mounted on four vibration isolation mounts located in the legs. The table floats on air bags located in the legs. The air bags were pressurized with a regulated supply of nitrogen at approximately 30 psi. Automatic leveling is supplied by regulators which control the nitrogen flow to and from each mount.

The components in the optical path were arranged as shown in Figure 2. The functions of the major components are as follows.

(1) A 10 milliwatt helium-neon laser with a 5 millimeter beam is the light source.

(2) The beam steering unit simply adjusts the height of the laser beam above the table and directs the beam in the desired direction. This unit is magnetically attached to the table.

(3) The shutter is used to control the exposure time of the photographic plate. It is isolated from the table by a rubber pad.

(4) The variable beam splitter and attenuator is a partially silvered mirror which both splits the reference and object beams and adjusts the relative intensity of the two beams to provide the required intensity at the photographic plate.

(5) The mirrors are used to direct the two beams and are placed so as to achieve approximately equal path lengths.

(6) The spatial filters consist of a microscope objective and pinhole mounted on a magnetic base. Their function is to remove irregularities in the beam due to imperfections or dirt on the beam splitter and mirrors. The microscope objectives also expand the beam.

(7) The photographic plate holder can be mounted either on a micropositioning base or inside the developing tank. It is made of 316 stainless steel and titanium and is impervious to film developing chemicals.

The specimens were supported in small vices bolted to aluminum stands which were bolted to the table. The stands were designed to allow mounting the vices in several different orientations or to mount a mechanical shaker.

The light meter used to determine the light intensity of the plate holder consisted of a planar diffused silicon PIN photodiode connected to a digital voltmeter. The photodiode was mounted in a small stainless steel tube, thus causing it to be highly directional. This unit was extremely sensitive to small changes in light intensity.

2. The Film Developing System

The film developing system was designed to allow in place developing for real-time holographic testing. The system performed so well that it was also used for double-exposure holography. The system as shown in Figure 3 included aspirator bottles to hold the chemicals, a pump for recirculation through the tank, and a light-tight cover for the developing tank. The major components were connected by valve manifolds as shown in Figure 4. Drain bottles on the floor were used to recycle chemicals after each use.

B. DESCRIPTION OF SPECIMENS

The four specimens used for the majority of this study were made from type 304 stainless steel pipe with an outside diameter of 1.86 inches and a 0.148 inch wall thickness. The pipe was cut into 1.50 foot lengths, and a saw cut was made in each specimen as shown in Figure 5. Two were cut with external flaws, one axial and one radial, and two with internal flaws, one axial and one radial. Each flaw was cut approximately one-quarter of the way through the pipe wall and was 0.062 inch wide. Aluminum plugs with an "O" ring seal were held in the ends of each pipe with four set screws. One plug was drilled and tapped to allow application of up to 250 psi internal pressure.

Two additional specimens were constructed from aluminum stock with internal axial grooves such as might be used in a fragmentation warhead as shown in Figure 6. One was cut

with symmetric grooves and the other with nonsymmetric grooves. The specimens were also plugged on the ends to allow internal pressurization.

C. HOLOGRAPHIC TEST PROCEDURE

1. Real-Time Holography

Real-time holography was used as a preliminary test of each type of specimen to determine the appropriate mode of excitation. A single exposure of the specimen was made and developed in-place in the developing tank. Kodak Type 131-02 holographic plate was used for all testing. The object and holographic plate were then illuminated again with the original beams, and the beam splitter was adjusted so the virtual image appeared about as bright as the actual object when viewed through the holographic plate. Various methods of excitation were then attempted. Heating of the outside of the pipe with a heat gun produced a very dramatic fringe pattern which tended to localize at the area where the heat was directed. The pattern shifted too rapidly to allow detection of a flaw even after the heat was removed. Heating of the inside of the pipe produced less dramatic but equally unstable fringe patterns. The application of five to ten pounds of force at several locations on the pipe produced interesting fringe patterns but difficulty in interpretation prevented this method from being useful for the detection of flaws.

The only method which resulted in detection of the axial internal flaw was internal pressurization. Since a

hydrostatic pressure of 100 psi was adequate for detection of this flaw, that pressure was chosen for initial testing of all of the pipe specimens.

2. Double-Exposure Holography

After the excitation method was determined, a double-exposure hologram was made of each pipe specimen. An exposure was made of the pipe in a rest state, a hydrostatic pressure of 100 psi was then applied, and a second exposure was made on the same holographic plate. After the plate was developed, it was illuminated with the original reference beam. The object beam was blocked. When the beam splitter was adjusted to provide maximum intensity to the reference beam, the image could be easily seen and photographed. As it was difficult to verify the location of the radial flaws using a 100 psi pressure, additional double-exposure holograms were made using higher pressures.

This same basic testing procedure was used for the testing of all specimens. Between 90 and 120 degrees of arc and six to eight inches of length could be seen clearly in each hologram. If this method were used to detect flaws at unknown locations, at least four holograms at 90-degree intervals must be made for each 6-inch increment of pipe.

3. Problems Encountered

There are many factors which must be optimized in order to produce clear holograms with meaningful fringe patterns. Initial attempts to make a hologram failed because of the momentary shock that the shutter was imparting

to the holographic table. The shutter caused a shock which lasted for approximately 1/30th of a second, the entire exposure time. By simply placing a small piece of rubber beneath the shutter, this problem was eliminated.

The coherence length of the laser utilized must be taken into account at all times. At one point in the testing, the optical components were arranged leaving a difference in the lengths of the reference beam path and object beam path of ten inches. While this was less than the coherence length of the laser, all holograms formed using this setup were very dim, and it was not possible to obtain a useful photograph of any of them. As the difference in the path lengths was reduced, the clarity and intensity of the resultant holograms improved greatly.

Another problem common to holographic interferometry is that the direction of displacement cannot be determined just by looking at a fringe pattern. This becomes more limiting as the complexity of the object under test increases. A knowledge of the direction of displacement is required for accurate interpretation.

IV. DATA REDUCTION AND ANALYSIS

A. FINITE ELEMENT METHODS UTILIZED

The expected surface displacement of each of the pipe specimens with predetermined flaws was computed using finite element programs. The pipes with internal and external axial flaws were modeled in two dimensions. A cross section of the pipe at the center of the flaw was used and the displacements at this location were later compared to the displacement at a section not affected by the flaw. Since the internal and external radial flaws were not adaptable to two-dimensional analysis, a three-dimensional model was utilized.

The program used for the two-dimensional analysis was PLISOP [6]. Twelve node rectangular elements were used. The service programs PLIMEG and PLILOAD were used to generate the final mesh and the consistent load vectors respectively. The twelve node elements allowed a cubic variation in the load intensity function. The final model used for both the internal and external axial flaws had 32 elements and 302 nodal points. The final mesh used for the case of the internal axial flaw is shown in Figure 7. As there was less than 10% difference in the displacements calculated by a 20 element solution and the 32 element solution, convergence was assured. The same degree of convergence was obtained between the 18 and 30 element models used for the case of the pipe with no flaw.

The displacements for the specimens with the internal and external radial flaws were computed using the program SAP IV which is a structural analysis program for static and dynamic response of linear systems [6]. Seventy-three cubic elements with 20 nodes each were used to model a one-inch, half section adjacent to the flaw. Each node, except those on the boundary, was free to translate in the X,Y and Z directions but not free to rotate. By elimination of the rotation, the number of equations in the resultant matrix was cut in half. The displacements calculated by this program for the points in the plane one inch away from the flaw were within 6% of those calculated for the pipe with no flaw using the two-dimensional model. This type of agreement lends credence to both solutions.

B. SURFACE DISPLACEMENT DETERMINATION

There are as many methods of interpretation of the fringe patterns formed by interferometric holography as there are references on the subject. Shibayama and Uchiyama [7] describe a method for the measurement of three-dimensional displacements which requires the recording of three simultaneous holograms of the surface under study. The holographic technique for this method is extremely difficult and not normally applicable to a nondestructive test situation.

The surface displacement can be found from a single interferometric hologram only if the direction of displacement is known. In the case of a pipe pressurized with a small internal

pressure, the direction of displacement can be assumed to be normal to the surface of the pipe. Several similar methods for the determination of surface displacement exist. Most of these methods differ in the choice of angles to be measured during hologram construction and viewing and in the assumptions made as to the description of the geometry involved.

The method of displacement measurement used in this project was presented in ENNOS [8]. Assumptions were made that the rays of illumination light were parallel and that the distance between the object and the holographic plate were large compared to the size of the object. If the geometry is as shown in Figure 8, the displacement is given by the equation

$$\text{Displacement} = d = \frac{N\lambda}{2 \cos \alpha \cos \psi}$$

where N is the number of bright fringes starting from a given reference point, λ is the wavelength of the light source, α is formed by the bisector of the angle between the illumination light and the direction of viewing, and ψ is the angle between the bisector and the displacement direction.

Due to the differences in the actual viewing and illumination directions from one end of the specimen to the other and due to the above method of data reduction, errors in displacement measurement up to 20% could have resulted for the angles involved. Further, a total error up to 40% is possible when the judgement error in counting fringes is taken into

account. The fewer the fringes, the higher this potential error. The errors due to the measurement problems above can be eliminated by using the methods of Burchett and Irwin for the measurement of radial deflections of cylinders [9], but the complexity of the method does not justify its use unless precise displacement measurements are required.

Figure 9 is a photograph of a double-exposure hologram of a bar which was displaced approximately 0.0002 inches at the left end between exposures. The right end was held rigidly in a vice. The above method of determining displacement shows that the left end of the bar was actually displaced 0.00024 inches.

V. RESULTS AND DISCUSSION

A. HOLOGRAPHIC TEST RESULTS FOR STANDARD PIPE SPECIMENS

Double-exposure holograms were initially made of the four pipe specimens with standard flaws using a hydrostatic pressure of 100 psi. The series of tests showed that the axial flaws were easily detected from the fringe patterns while the radial flaws were very difficult to detect. The interference patterns formed by the external and internal radial flaws were the same as those formed from a pipe with no flaw subjected to an internal pressure of 100 psi. A slight fringe deflection at the point where the fringe passed over the flaw was the only indication of the existence of the radial saw cuts. The internal axial flaw was clearly outlined by a symmetric fringe around the cut as shown in Figure 10. The tape shown in this figure was applied to the surface of the pipe and marked at one-quarter inch intervals. The external axial saw cut gave a fringe pattern similar to that from a specimen with no flaw except that an additional fringe seemed to start in the center of the cut.

The next series of holograms was made using an internal pressure of 150 psi to stress the pipe. The fringe patterns were similar to those formed at 100 psi except that more fringes were formed around the axial flaws and the fringe deflections over the radial flaws were more pronounced. Figure 11 shows the pipe with the internal axial flaw at 150 psi internal pressure. The tape used to mark the surface bubbled

as the pipe expanded and caused a disturbance in the fringe pattern. The hologram of the pipe with the external axial flaw is shown in Figure 12.

Figures 13 and 14 are holograms of the pipe with the internal and external radial flaws. Note that the fringe deflects toward the center of the internal flaw and away from the center of the external flaw. That is because the internal flaw causes an indentation of the pipe surface over the flaw when the pipe is pressurized while the external flaw causes a bulge. Figure 15 is a hologram of the pipe with the external radial flaw at 200 psi. The fringe deflection in this hologram is much more pronounced than it was with only 150 psi. Higher pressures were not considered safe as the end plugs were only held in the pipes with set screws.

B. COMPARISON OF HOLOGRAPHIC RESULTS WITH FINITE ELEMENT CALCULATIONS

The finite analysis of the pipe deformation was conducted using an internal pressure of 150 psi. As the two cases involving internal flaws were analyzed using a two-dimensional program, the only comparison possible between the holographic and finite element results was to compare the relative displacements at the center of the flaw and a point on the pipe not affected by the flaw. For analysis purposes the point not affected by the flaw was arbitrarily selected as the reference point. It was located on the surface of the pipe on a plane perpendicular to the axis of the pipe 1½ inches from the end or 3 inches from the center of the flaw. Figure

16 is a graph of the displacements relative to this point as measured by counting the fringes on the holograms for the pipes with the internal and external axial flaws. These measurements were made along the axis of the pipe containing the center of the flaw. The computed value is shown as a straight dashed line because only the value at the center of the flaw was actually calculated. The internal flaw caused a depression in the surface of the pipe while the surface around the external flaw deformed more than the surrounding area. The measured depression at the center of the internal axial flaw was 32% deeper than the computed value. The measured elevation at the center of the external axial flaw was 16% higher than the computed value. The major contribution to these errors is the fact that there are so few fringes involved that a half fringe error in counting will result in a large error in the measured value. Also, there was up to a 10% difference in the wall thickness in some sections from which the specimens were made. This apparently was responsible for the lack of symmetry seen in some of the fringe patterns.

As can be seen from Figure 17, the relative displacements at the radial flaws for 150 psi pressure were less than what is generally considered to be the minimum sensitivity of this method. The minimum sensitivity is a displacement of 1/10th of the wavelength of the coherent light source. A quantitative comparison of the computed and measured values for these specimens was not possible as there were no fringes to count.

C. HOLOGRAPHIC TEST RESULTS FOR ADDITIONAL SPECIMENS

The large aluminum pipes with symmetric and nonsymmetric grooves were tested using internal pressures ranging from 100 psi to 470 psi. The external markings on the pipes did not show clearly in the holograms making it impossible to correlate the location of the fringes with the location of the internal flaws, but the high and low spots on the strained specimen were obvious in the hologram. The fringe pattern of the pipe with the symmetric grooves was obviously different from that of the pipe with nonsymmetric grooves. Figures 18 and 19 are holograms of the pipe with nonsymmetric grooves at 310 and 470 psi respectively. Figure 20 shows the pipe with symmetric grooves at 340 psi. This method of testing shows great promise for the determination of the effects of various types of grooves on fragmentation by nondestructive means.

Several attempts were made to detect flaws in welded and silver braised joints in pipes. These flaws had previously been detected by either radiographic or ultrasonic testing. The attempts to relocate these flaws using interferometric holography failed either because the pressure used was too low or the flaws were too small to affect the strength of the specimen. More research is required to compare the abilities of holographic nondestructive testing with existing methods.

VI. CONCLUSIONS

This study led to the following conclusions:

1. Interferometric holography is most effective in detecting flaws in pipes under the following conditions:

   a) An internal pressure is used for excitation of the specimen. Higher pressures generally will allow the detection of smaller flaws.

   b) The flaw is large enough to affect the strength of the pipe. Small flaws which do not significantly affect the strength of the specimen cannot be detected by this method.

   c) The flaw is located in the quadrant of the pipe which is illuminated. At least four holograms should be made around the circumference of a pipe to insure the detection of all flaws.

   d) The method of support of the pipe must be known to prevent false indication of flaws.

   e) The surface displacement near the flaw must be at least 10% of the wavelength of the light source greater than or less than that of the surrounding area to insure detection.

2. The location and orientation of the flaws has a great effect on its detectability. Radial flaws produce smaller deflections than axial flaws and therefore are harder to detect. For the four cases studied, both of the internal flaws resulted in a depression of the surface around the flaw

while the external flaws resulted in a hump in the surface when the pipes were pressurized (Figures 16 and 17).

3. Nonuniform wall thickness will distort the interference pattern and therefore can be detected by interferometric holography.

4. The prediction of fracture patterns in shell casings with different types of grooves is an area of research where this method of testing could prove most profitable. The stress pattern in the pipe is directly linked to the displacement at the surface when the specimen is pressurized. The lines of maximum and minimum displacement can be readily identified by holographic methods.

5. The correlation between finite element calculations and holographic measurements of surface displacement was acceptable. Since the finite element programs which were used predict stresses as well as displacements throughout the structure, they are invaluable tools in the determination of what pressure should be used for a particular specimen to detect different sizes and types of flaws without exceeding stress limits.

6. Pulsed lasers used together with modern high speed holographic plate should allow the extension of these methods from the laboratory to the field. Shorter exposure times makes holography less susceptible to low frequency vibration. The massive vibration isolation table used to isolate the system from low frequency vibration is no longer required.

VII. RECOMMENDATIONS FOR FURTHER STUDY

Additional study in the following areas could greatly increase the usefulness of interferometric nondestructive testing:

1. A computer study to determine the minimum detectable flaw size in various classes of pipes and the pressure that must be used for excitation to detect that flaw should be made.
2. A practical study to compare the ability to detect flaws holographically to the ability to test the same flaw by conventional methods would be useful.
3. A practical study to determine the ability to detect naturally occurring flaws such as corrosion pits and cracks should be made.
4. The potential to use holography to nondestructively predict failure modes for specimens with various internal grooves has been demonstrated. The next logical step is to compare finite element results to holographic results and finally verify the results with actual destructive testing. This method could significantly reduce the number of specimens required for destructive testing.

APPENDIX A

CARE AND USE OF THE HOLOGRAPHIC SYSTEM

A. SAFETY PRECAUTIONS

1. When the laser is in use, a sign must be placed outside the door of the laboratory The sign shall read "CAUTION LASER LIGHT."

2. People present in the laboratory shall be warned prior to energizing the laser.

3. Do not look directly into an unexpanded laser beam.

4. Do not exceed 100 psi supply pressure to the table isolation system.

5. The floor around the holographic table must be kept clear of obstructions.

B. OPERATION OF THE HOLOGRAPHY SYSTEM

1. General

The holographic system should be set up as shown in Figures 1 and 2 when conducting real-time or double-exposure holography. The path lengths of the reference beam and the object beam should be as nearly equal as possible and in no case should differ by more than 6 inches. The path length is the total distance the light must travel from the beam splitter to the holographic plate. All optical components should be magnetically attached to the table top. The specimen holder and film plate holder should be bolted rigidly to the table. The shutter should be placed on a thin sheet of foam rubber to isolate it from the table.

2. Operation of the Holographic Table

The holographic table is isolated from low frequency vibrations in the floor by pneumatic isolation mounts. These mounts also provide an automatic leveling feature. Only dry air or nitrogen should be used in the isolation system. The maximum safe operating pressure is 100 psi under load and 60 psi unloaded. The supply gas pressure must be regulated and set at 5 to 10 psi above the highest reading gauge on the mounts. If hunting or oscillation occurs, reduce the supply pressure until it stops. The neutral floating height of the table may be adjusted by turning the height control knob on each leveling valve. The gas supply should be secured when the table is not in use.

The stainless steel table top is drilled with ¼ - 20 holes on one-inch centers. Stainless steel screws should be used to fasten components to the table whenever possible.

3. Determination of Holograph Exposure

The object beam and reference beam should have approximately the same intensity at the holographic plate to construct holograms with good contrast. To achieve equal intensity, place the photo diode behind the center of the plate holder and point it in the direction bisecting the two incoming beams. Insure that the polarity is such that the digital volt meter (DVM) reads on the positive scale. The voltage range switch should be on the one volt setting.

With the scene beam blocked, adjust the beam splitter so that the reference beam gives a reading of approximately

0.0200 volts. Now block the reference beam and adjust the scene beam to obtain the same reading on the DVM. With both beams exposed, the DVM should now read approximately 0.0400 volts. With this light intensity use an exposure time of one-half second for a single exposure hologram or one-quarter second for a dual exposure.

Other exposures which have been successful are one-quarter second at an intensity of 0.0800 volts and one thirtieth second at 0.2000 volts. As the output of the photo-diode is not linear, the correct exposure for other light intensities will have to be found by trial and error. The correct exposure may also vary from one box of film to the next.

The above exposures apply only when using Kodak high speed holographic plate Type 131-02 which requires an exposure of 4 to 5 ergs/cm^2 for maximum reconstruction brightness.

4. Exposing the Holographic Plate

The next step after adjusting the scene and reference beams for the correct exposure is the exposure of the holographic plate. The following procedure applies to the formation of a dual-exposure hologram. If a single exposure hologram is to be formed, simply omit the second exposure. With the room totally darkened, proceed as follows:

a. Insure the table top is floating freely.

b. Place a holographic plate in the plate holder. Insure that it is clamped tightly in place.

c. Energize the laser, release the shutter and de-energize the laser. This step should be completed quickly to prevent stray reflected light from exposing the holographic plate.

d. Place the light-tight cover over the plate holder.

e. Turn on the room lights and excite the specimen by whatever method is to be utilized.

f. Darken the room, remove the light-tight cover, and expose the holographic plate for the second time.

g. Replace the light-tight cover. The holographic plate is now ready to be developed.

C. HOLOGRAM DEVELOPING TECHNIQUES

1. General

The in-place developing system is shown in Figures 3 and 4. Drain bottles under the table are used to recycle the film processing chemicals after each rinse. The peristaltic pump is used to circulate the chemicals during each rinse. A setting of 4 or 5 on the pump speed control provides sufficient circulation. The developing tank is gravity filled by opening the appropriate valve on the fill-valve manifold and drained by opening the drain valve. Care must be taken not to overfill the developing tank as the chemicals are highly corrosive to the holographic table. Spills should be wiped up immediately. Chemicals should be maintained at 65 to 70 degrees F.

2. <u>Procedure for Developing Kodak Type 131-02 Holographic Plate</u>

a. Rinse in Kodak D-19 Developer for 6 to 8 minutes.

b. Rinse in Indicating Acid Stop Bath for 10 to 30 seconds.

c. Fix using Kodak Fixer for 6 to 8 minutes. The light-tight cover may be removed from the developing tank after this step.

d. Wash in demineralized water for 7 to 10 minutes.

e. Rinse in a solution of one part methanol and one part water for 7 to 10 minutes. If the plate retains a blue tint after this rinse, either the rinse time was too short or the methanol solution requires replacement.

f. Wash again in water for 5 to 8 minutes.

D. HOLOGRAM RECONSTRUCTION TECHNIQUES

In the case of real-time interferometric holography, the image is reconstructed simply by shining the original reference and scene beams on the scene and the plate. The reconstructed image is superimposed directly on top of the original subject and is viewed by looking through the back of the holographic plate toward the subject. If the plate and object are in exactly the same location as when the plate was exposed, it will be impossible to distinguish the hologram from the object. The beam splitter is adjusted to give a clear reconstruction. Small displacements of the object will then cause interference fringes to appear.

For double-exposure interferometric holography, the image is reconstructed by blocking the subject beam and again looking through the back of the plate which is illuminated only by the reference beam. The original object can be removed or left in place. The reconstructed image will again appear in the same location as the original object.

In either of the above cases the reconstructed image can be photographed using either Type 55 Polaroid film or Kodak SO-115 Holographic Reconstruction Film.

E. CARE AND MAINTENANCE

The following guidelines should be followed to keep the holographic stem in good working order.

1. Keep the table top clean. Wipe up all spills immediately. Wipe down the table top weekly when in use. Dirt or scratches will result in the inability to mount optical components properly. Keep the table and all optical components covered when not in use to prevent dust accumulation.

2. Care must be taken to keep all optical surfaces clean. If smudges or dirt accumulate on any of the mirrors, they should be cleaned with acetone on a soft lens tissue. Use each portion of the tissue only once. Rub softly in one direction to prevent scratching the surface. Be careful not to get the acetone on painted surfaces.

3. Pinholes and microscope objectives should be stored in their respective dustproof boxes when not in use on the spatial filter assembly. When adjusting the spatial filter assembly, care must be taken not to bring the microscope

objective into contact with the pinhole as this can damage the pinhole.

4. The laser power supply should not be energized when the laser is not connected. The laser should only be energized when it is actually needed.

5. The film developing system should be inspected for leaks daily. The film developing tank should be cleaned at least weekly when in use.

6. Film developing chemicals in general can be used to develop 15 to 25 holograms. If the stop bath loses its characteristic yellow color or turns purple, it should be replaced. If the methanol solution fails to remove all of the blue emulsion or turns cloudy, all of the chemicals should be replaced.

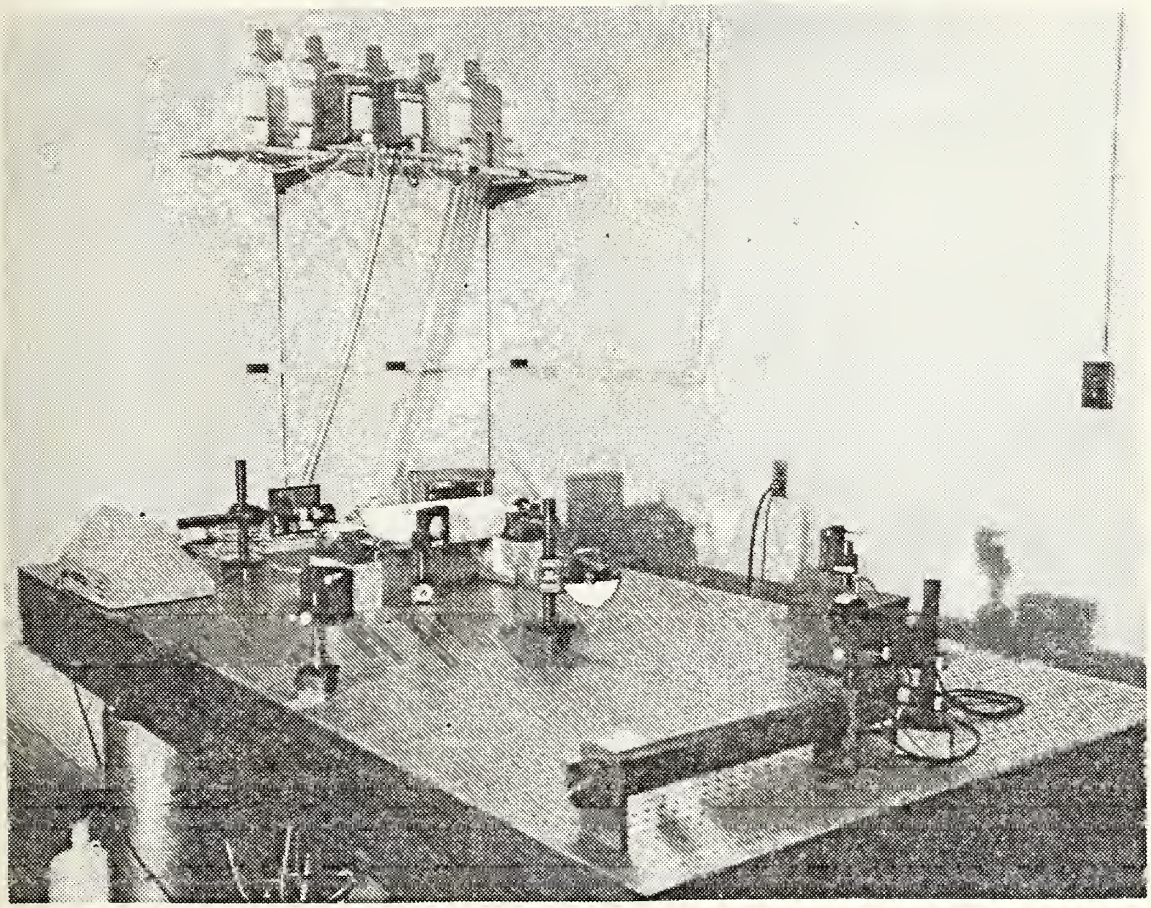


FIGURE 1. Photograph of Holographic System

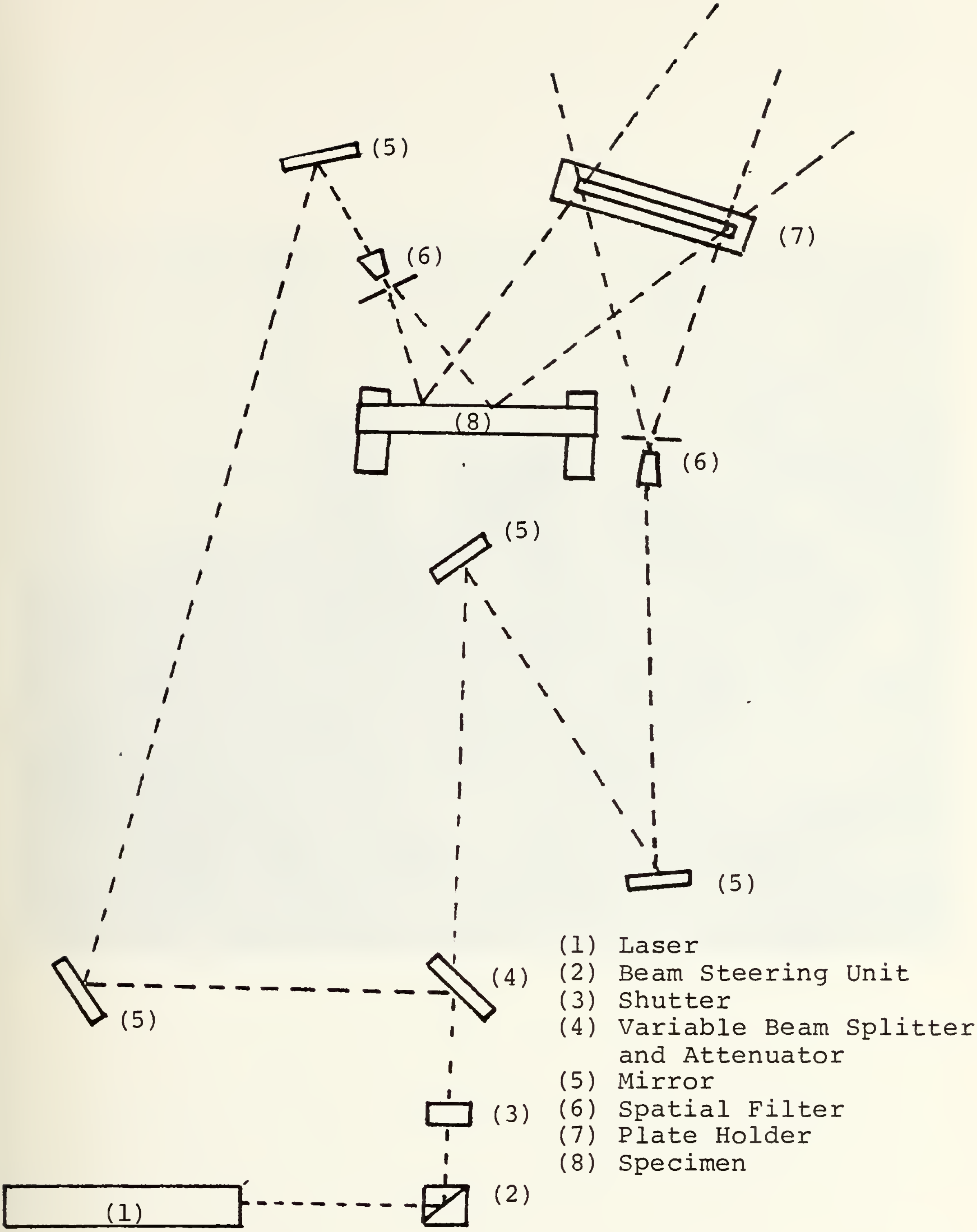


FIGURE 2. Schematic of Holographic System

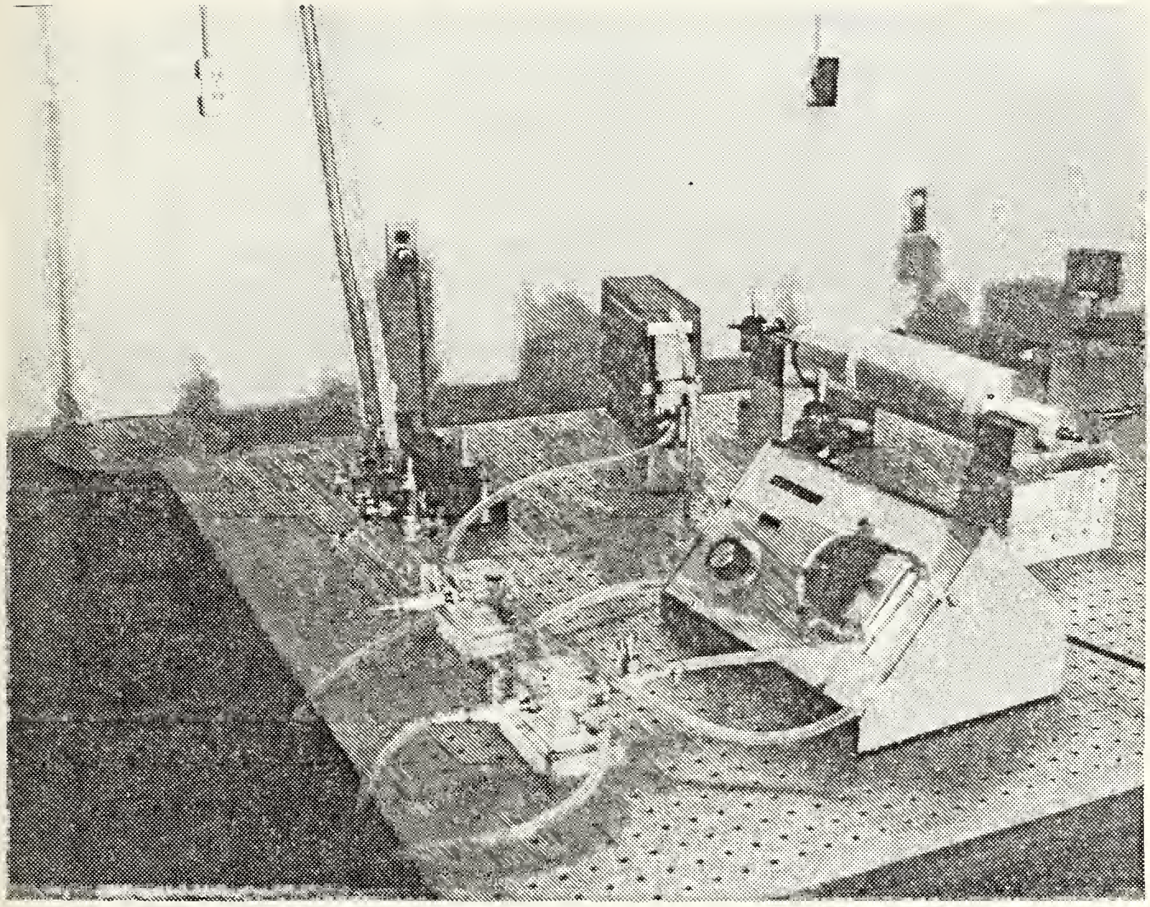
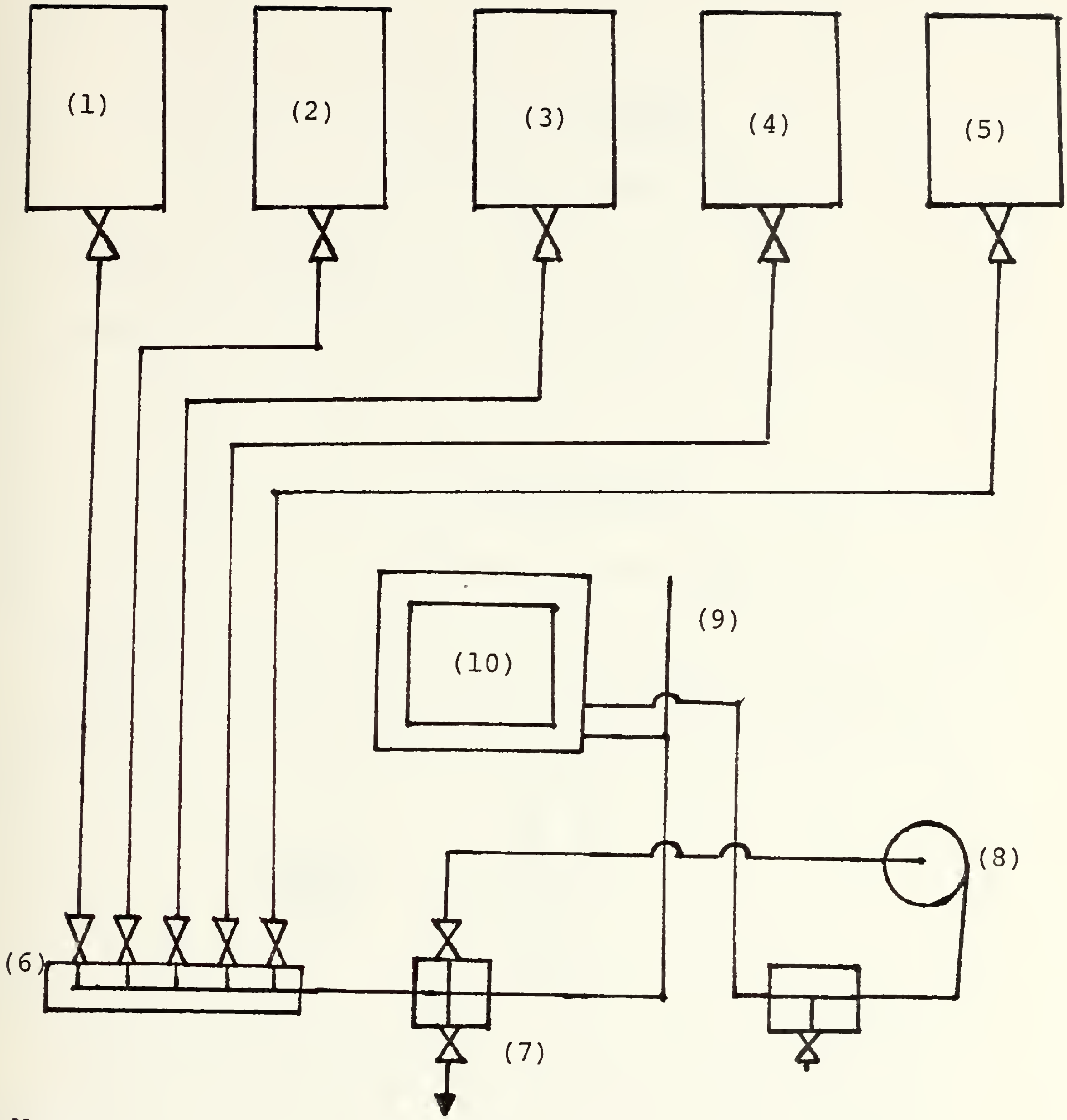


FIGURE 3. Photograph of Film Developing System



(1) Water
(2) Developer
(3) Stop Bath
(4) Fixer
(5) Methanol

(6) Fill Valve Manifold
(7) Drain Valve
(8) Recirculation Pump
(9) Level Gage
(10) Developing Tank

FIGURE 4. Schematic of Film Developing System

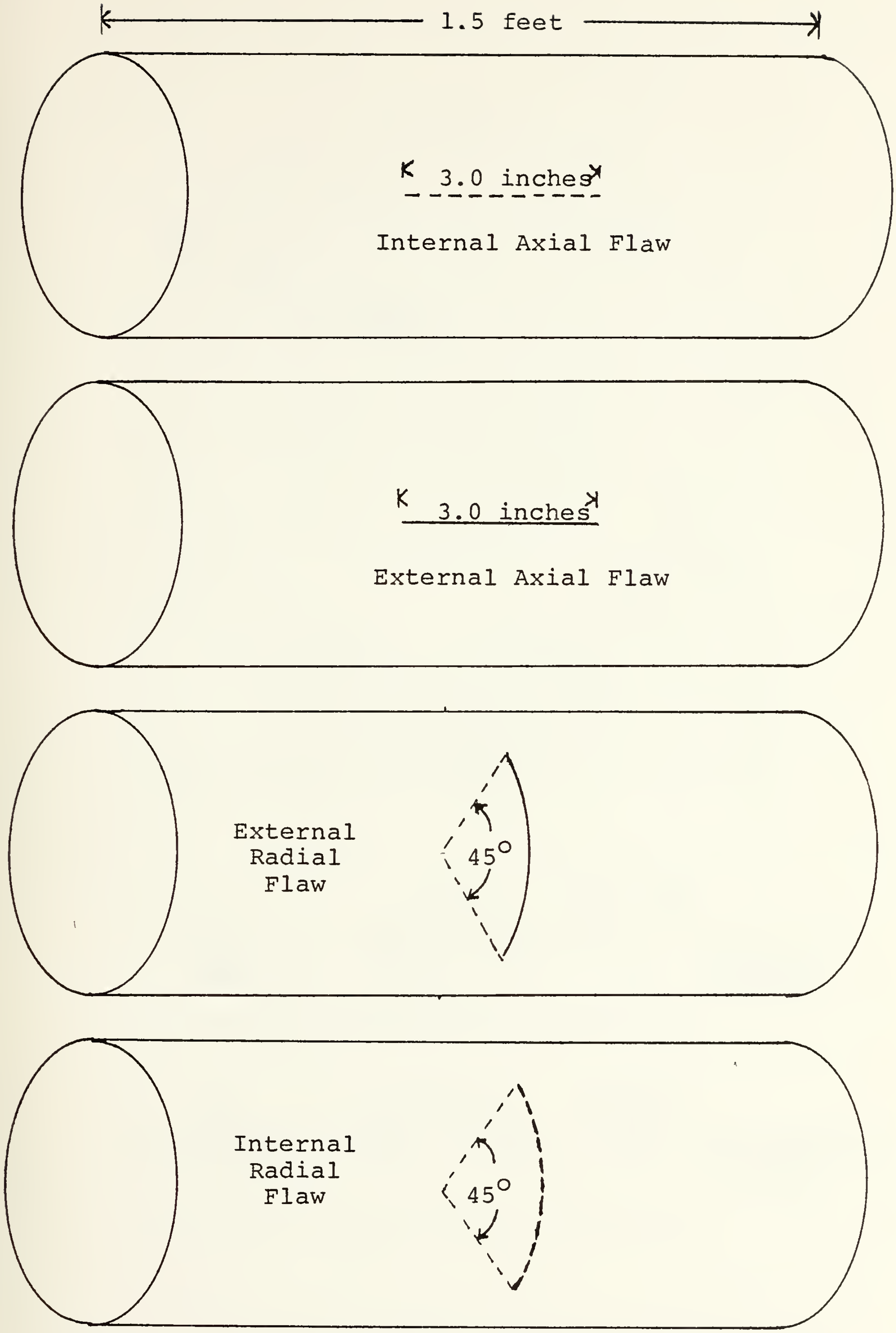


FIGURE 5. Test Specimens - Pipe Sections

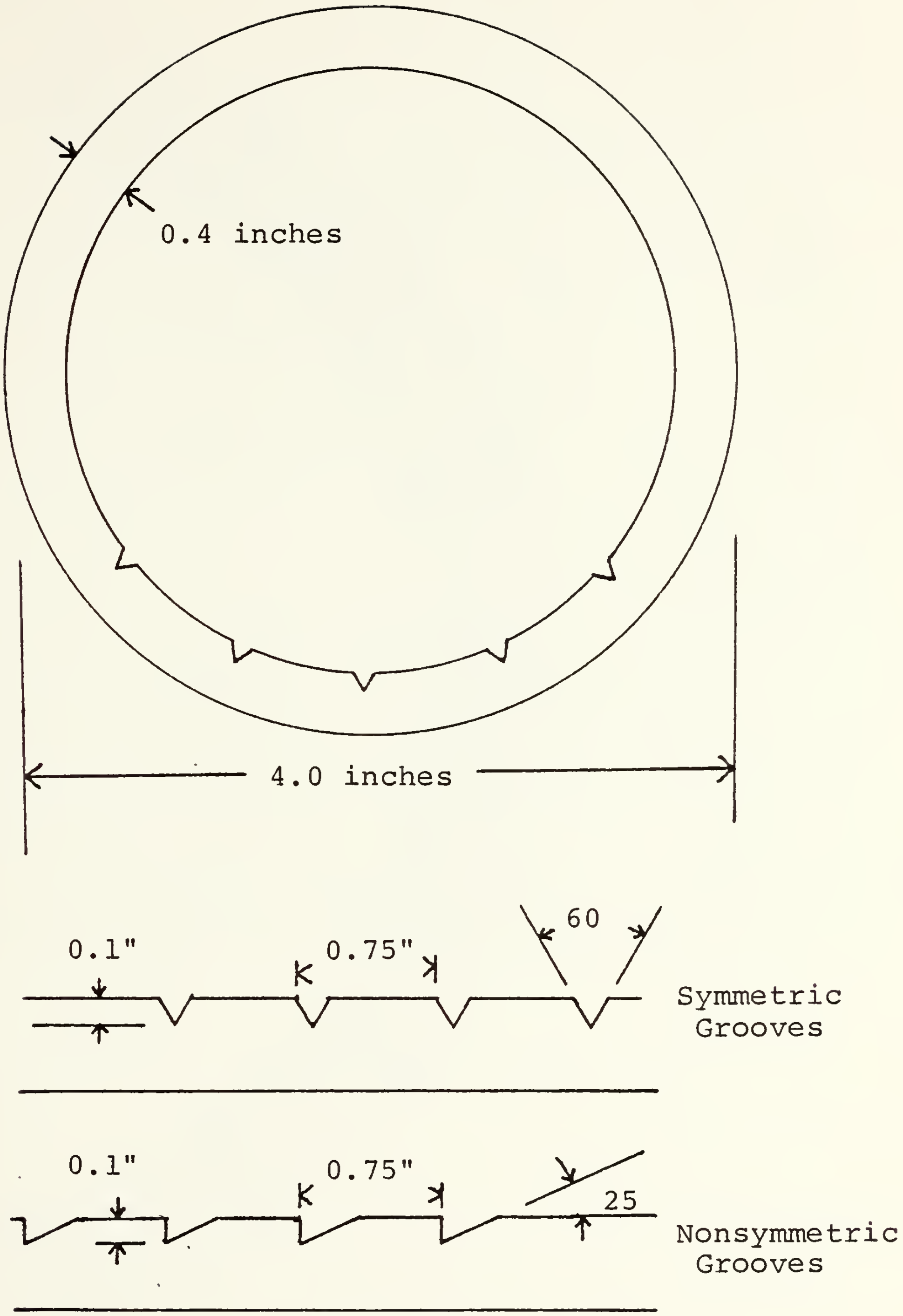


FIGURE 6. Test Specimens - Fragmentation Casings

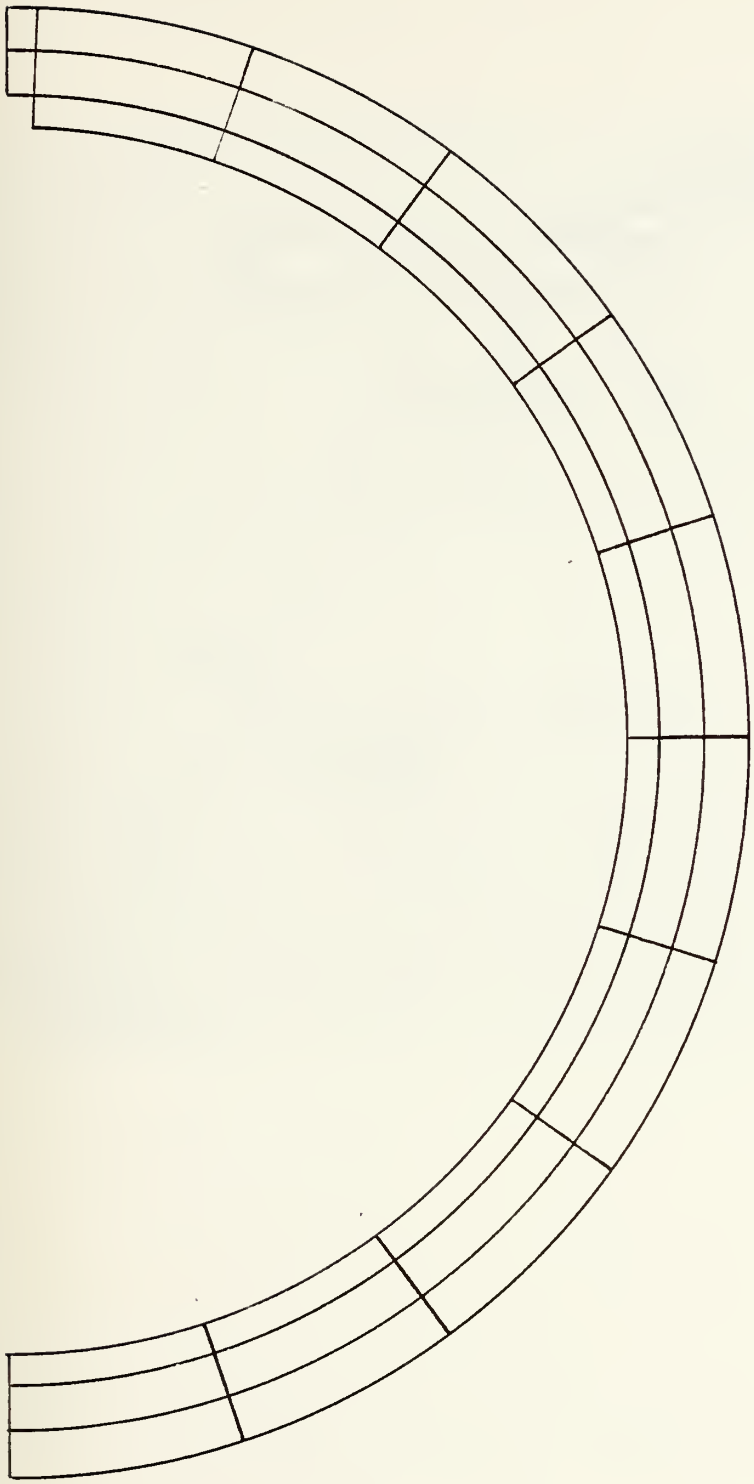


FIGURE 7. Finite Element Mesh for Internal Axial Flaw

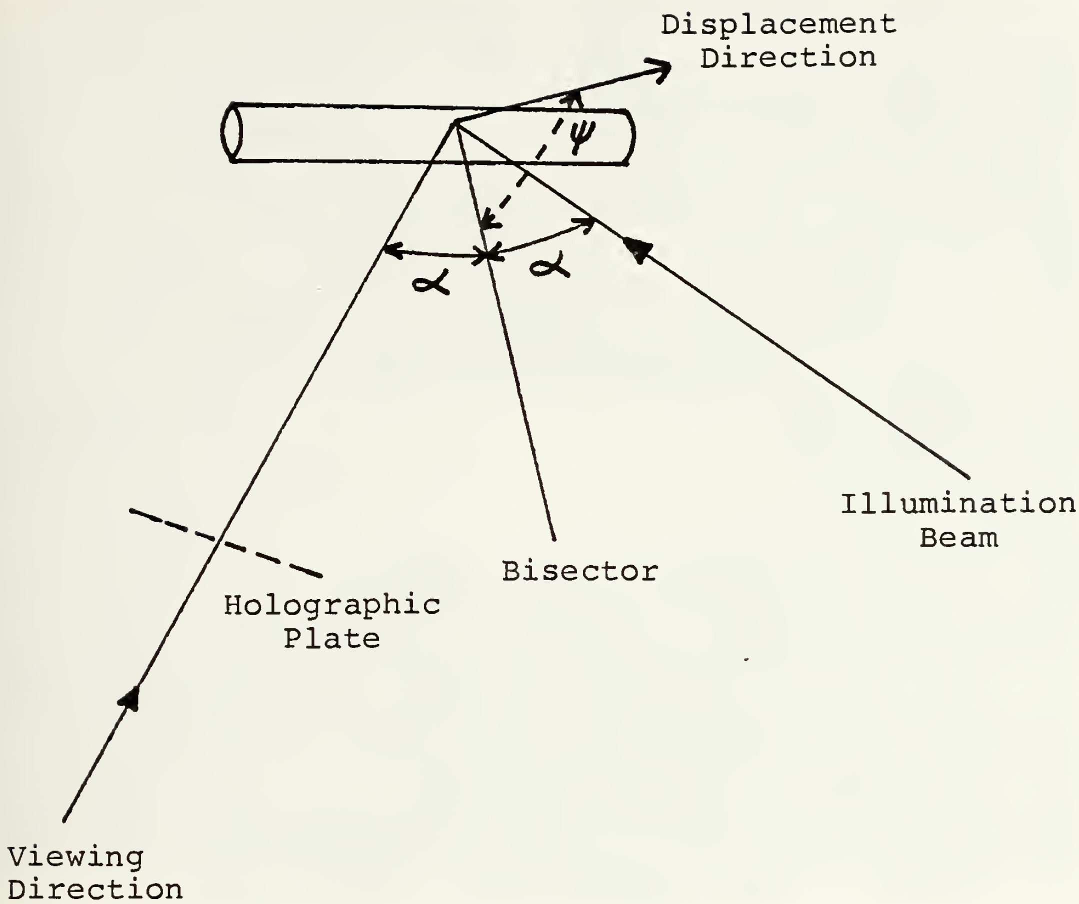


FIGURE 8. Geometry for Determination of Surface Displacement

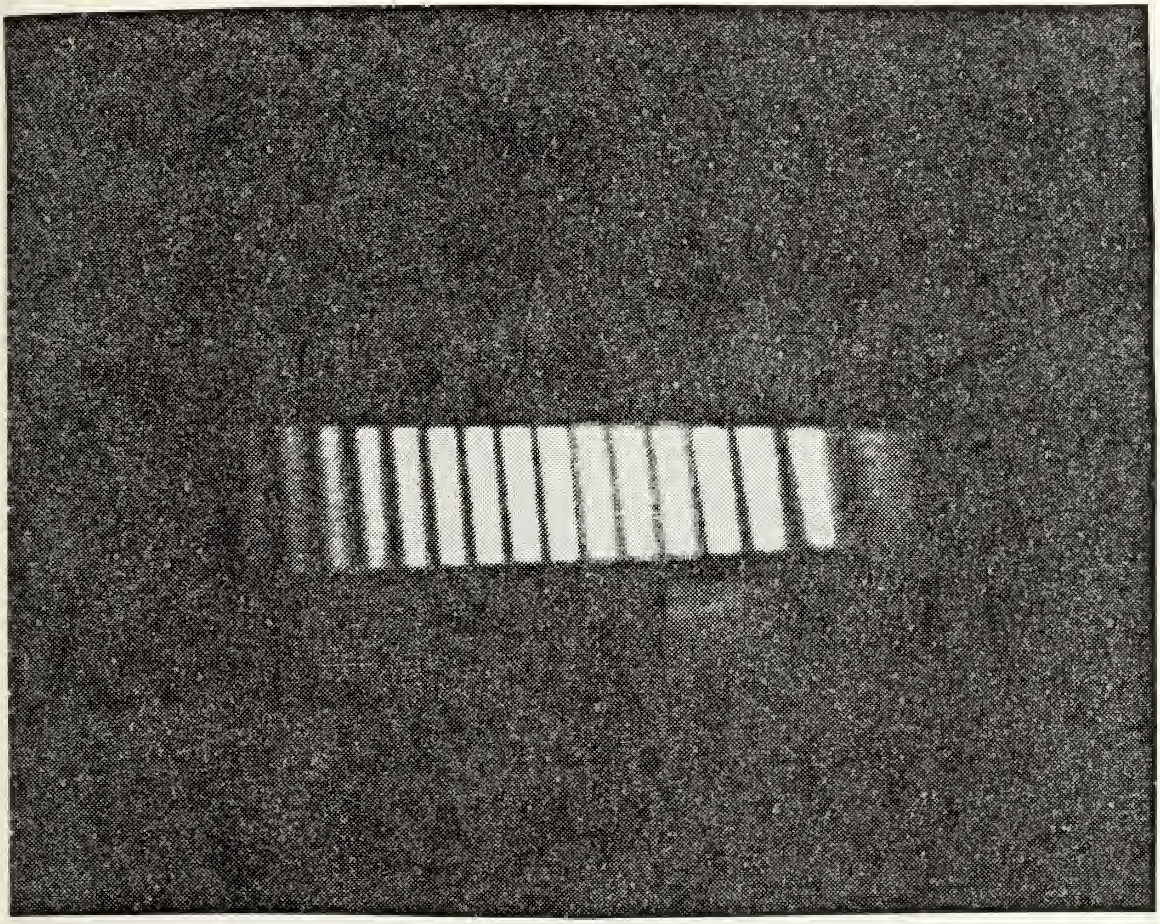


FIGURE 9. Double-Exposure Hologram of Cantilever Beam Displaced 0.0002 Inches at Left End Between Exposures

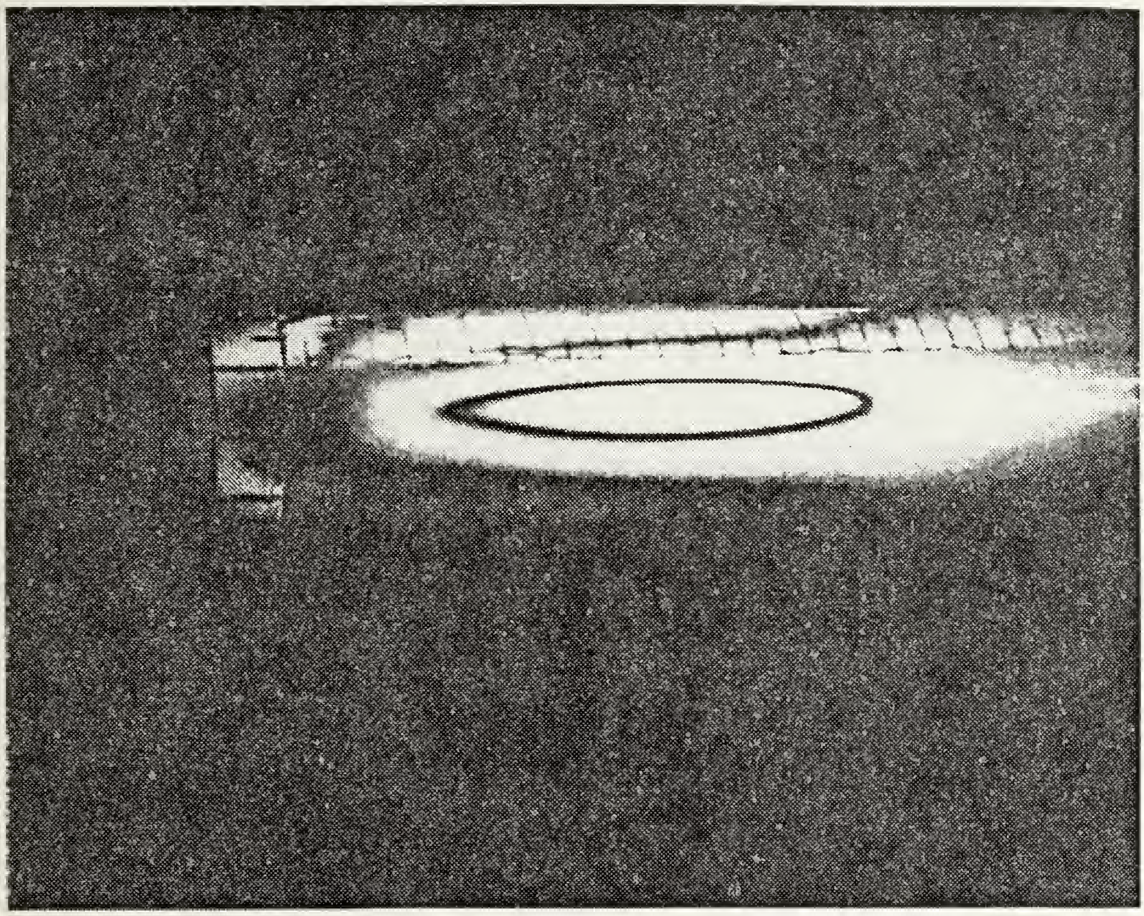


FIGURE 10. Double-Exposure Hologram of Pipe with Internal Axial Flaw Pressurized to 100 psi Between Exposures

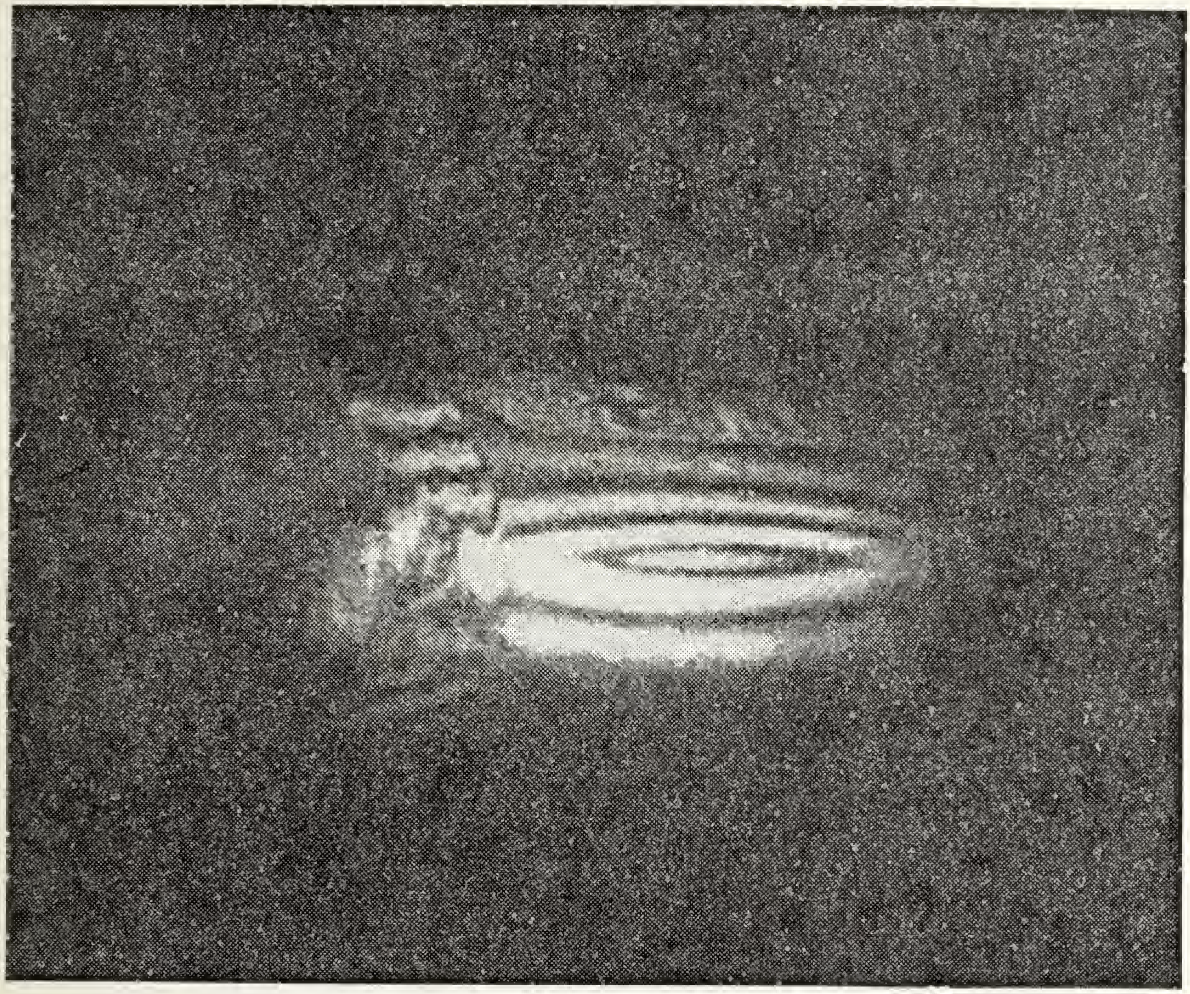


FIGURE 11. Double-Exposure Hologram of Pipe with Internal Axial Flaw Pressurized to 150 psi Between Exposures

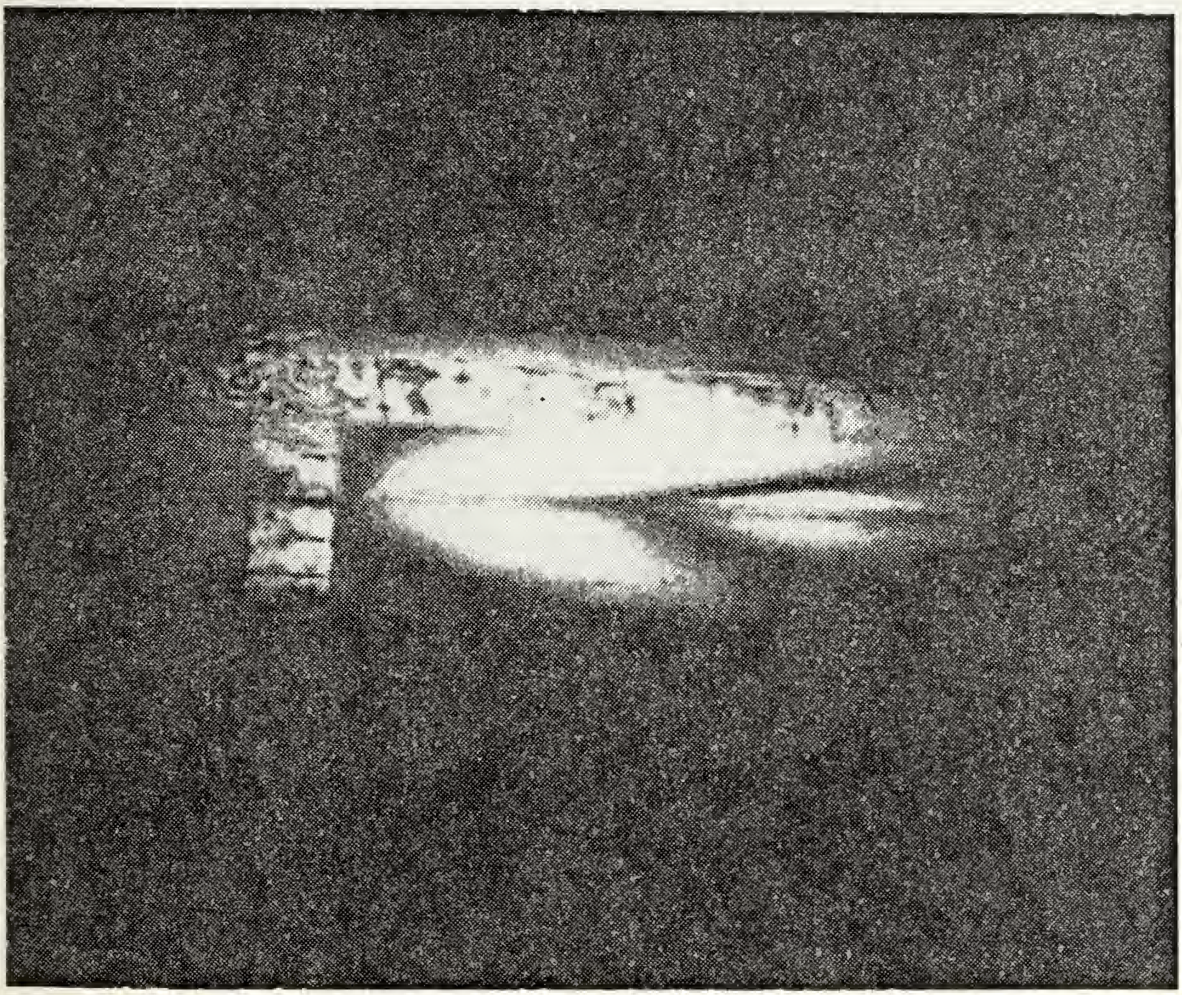


FIGURE 12. Double-Exposure Hologram of Pipe with External Axial Flaw Pressurized to 150 psi Between Exposures

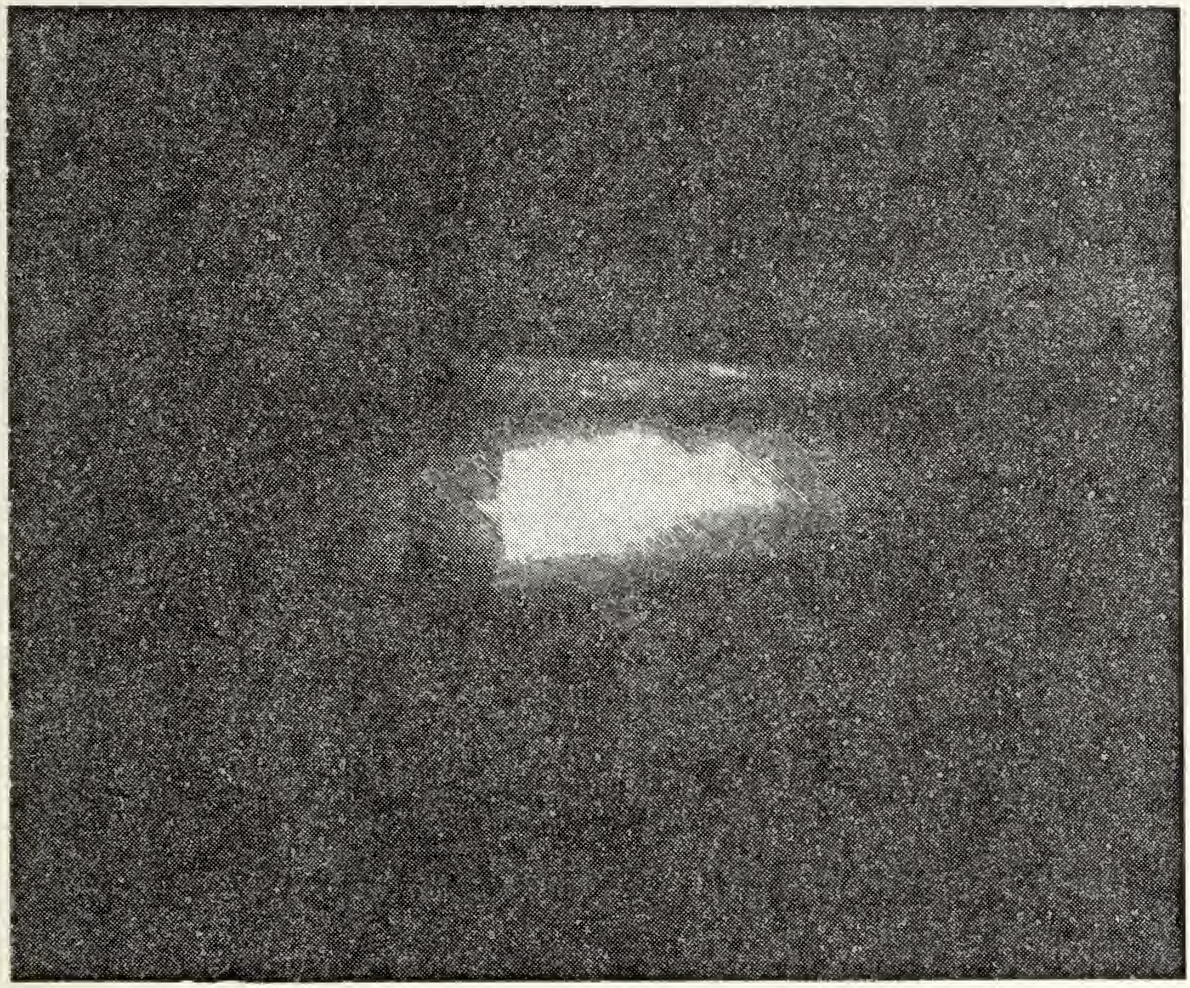


FIGURE 13. Double-Exposure Hologram of Pipe with Internal Radial Flaw Pressurized to 150 psi Between Exposures

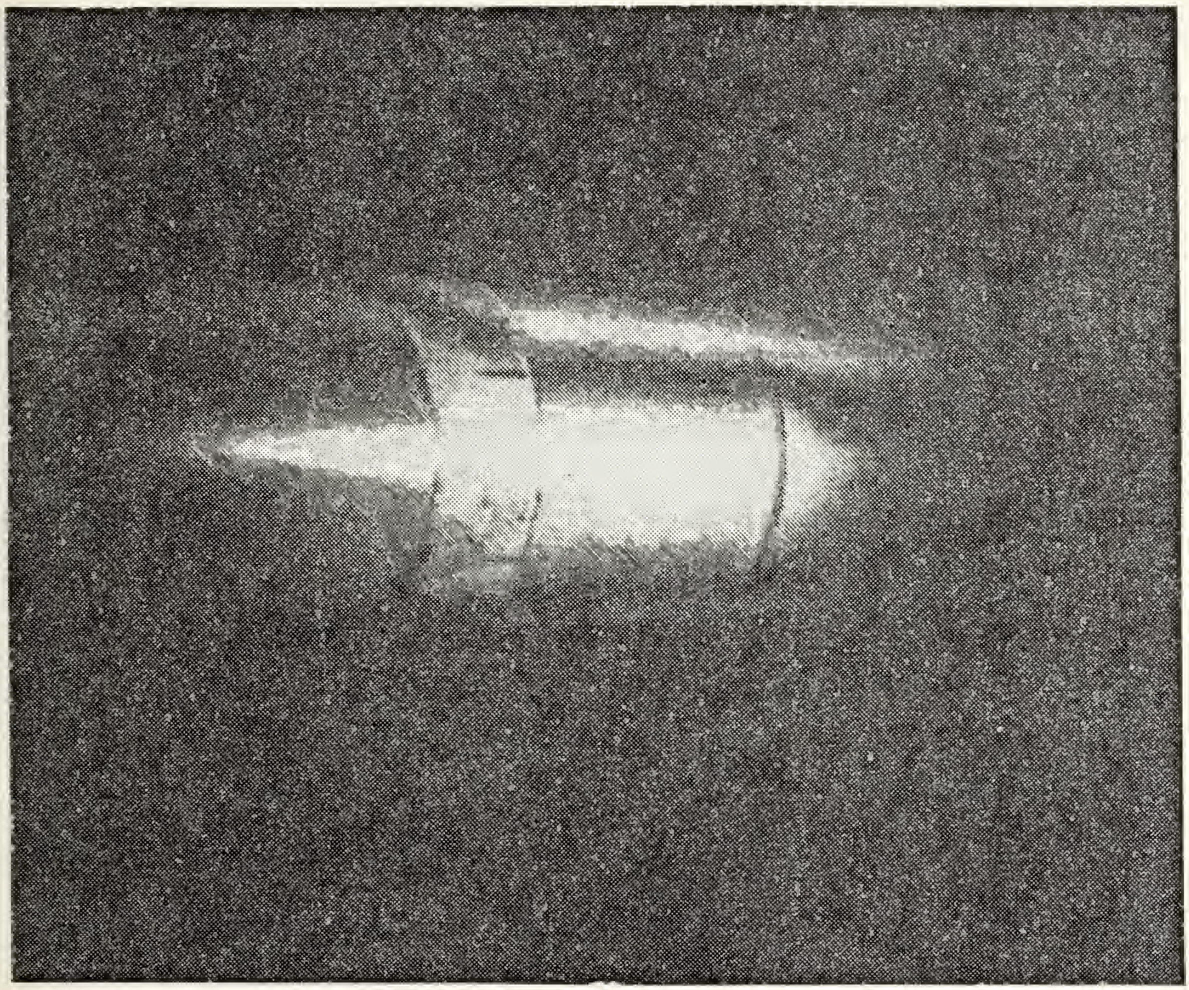


FIGURE 14. Double-Exposure Hologram of Pipe with External Radial Flaw Pressurized to 150 psi Between Exposures

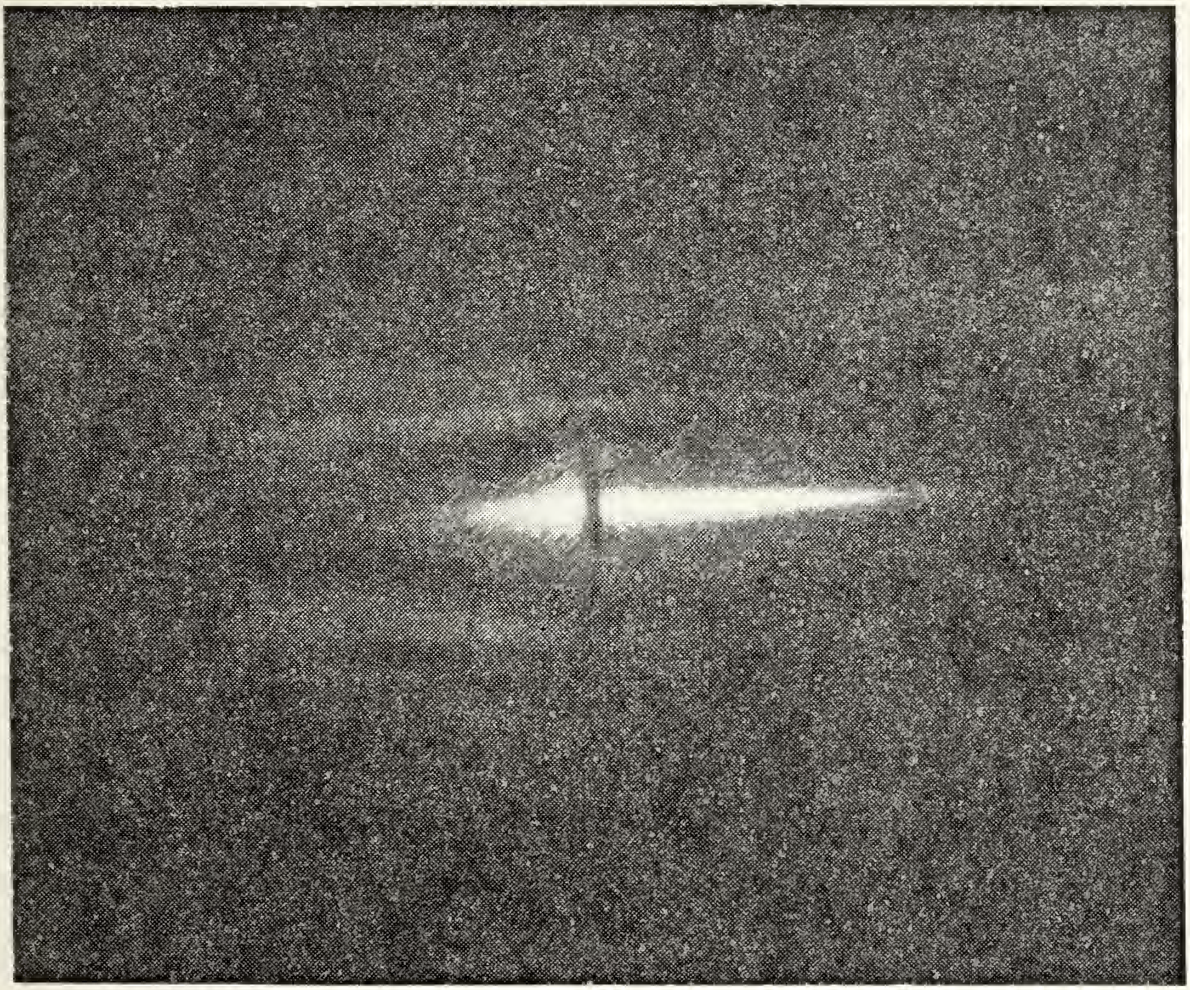


FIGURE 15. Double-Exposure Hologram of Pipe with External Radial Flaw Pressurized to 200 psi Between Exposures

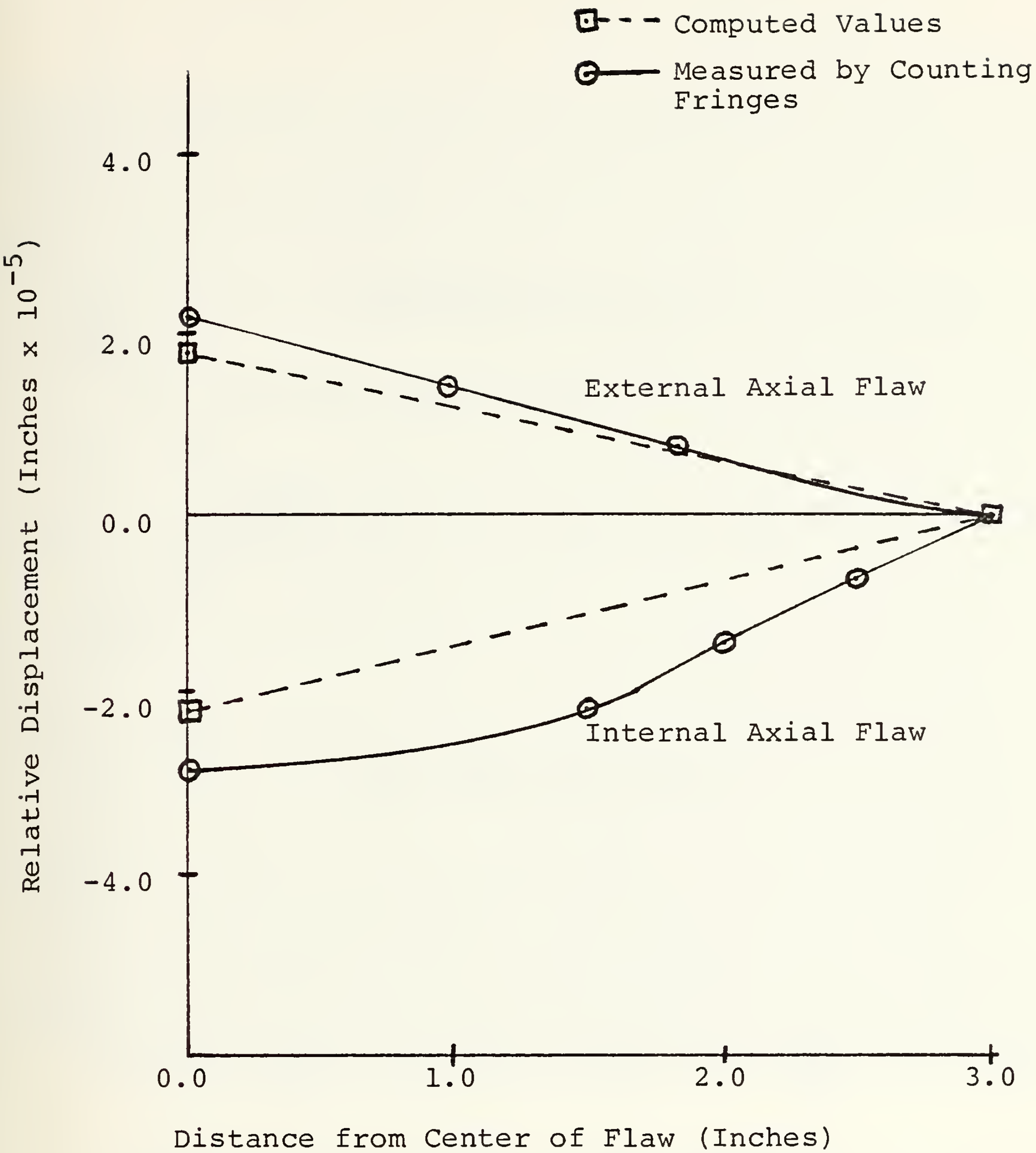


FIGURE 16. Displacement Relative to Point Unaffected by Flaw Measured Along Axis of Flaw for Pipes with Internal and External Axial Flaws Pressurized to 150 psi.

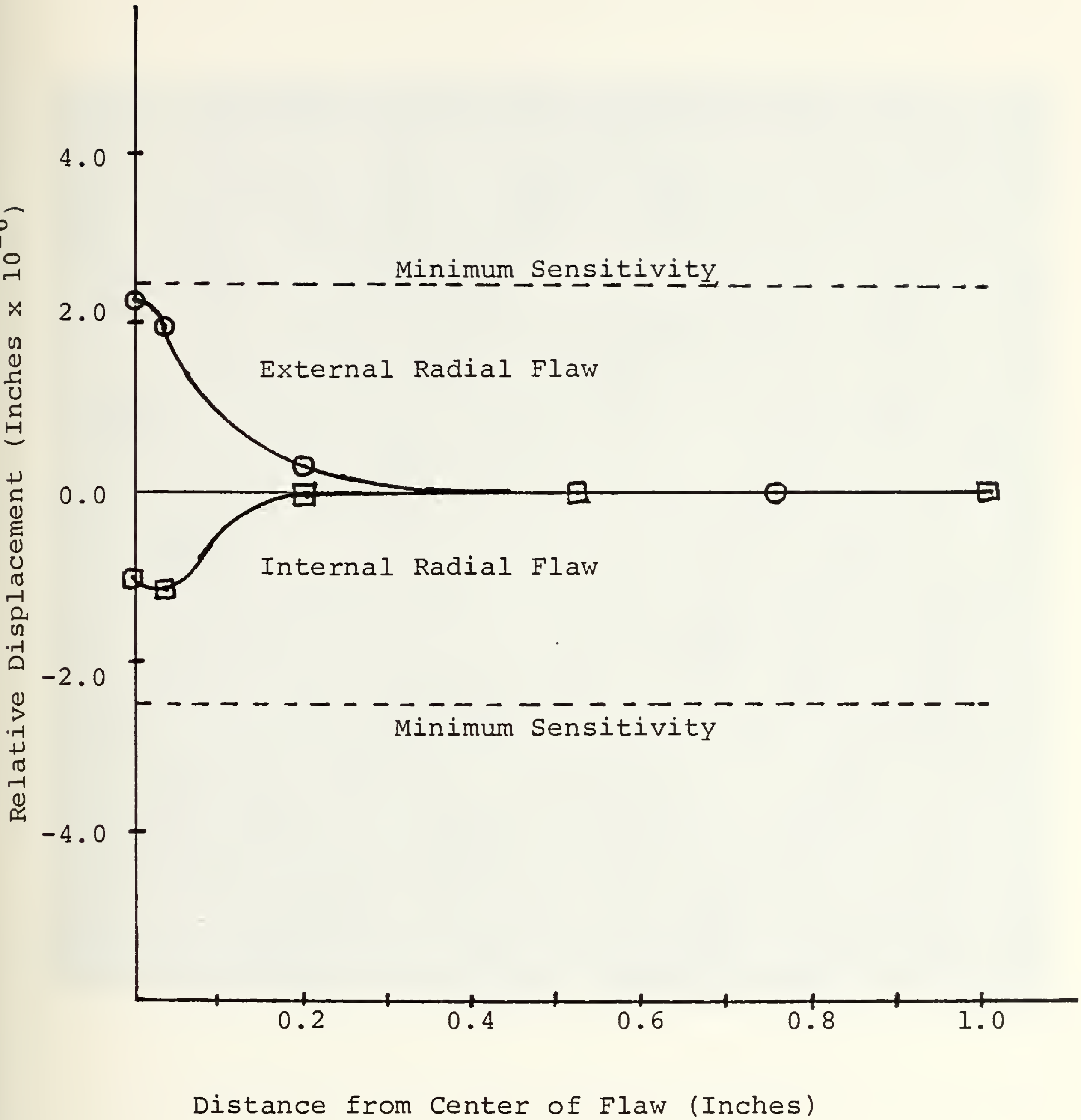


FIGURE 17. Displacement Relative to Point Unaffected by Flaw Mearured Along Axis of Center of Flaw for Pipes with Radial Flaws Pressurized to 150 psi.

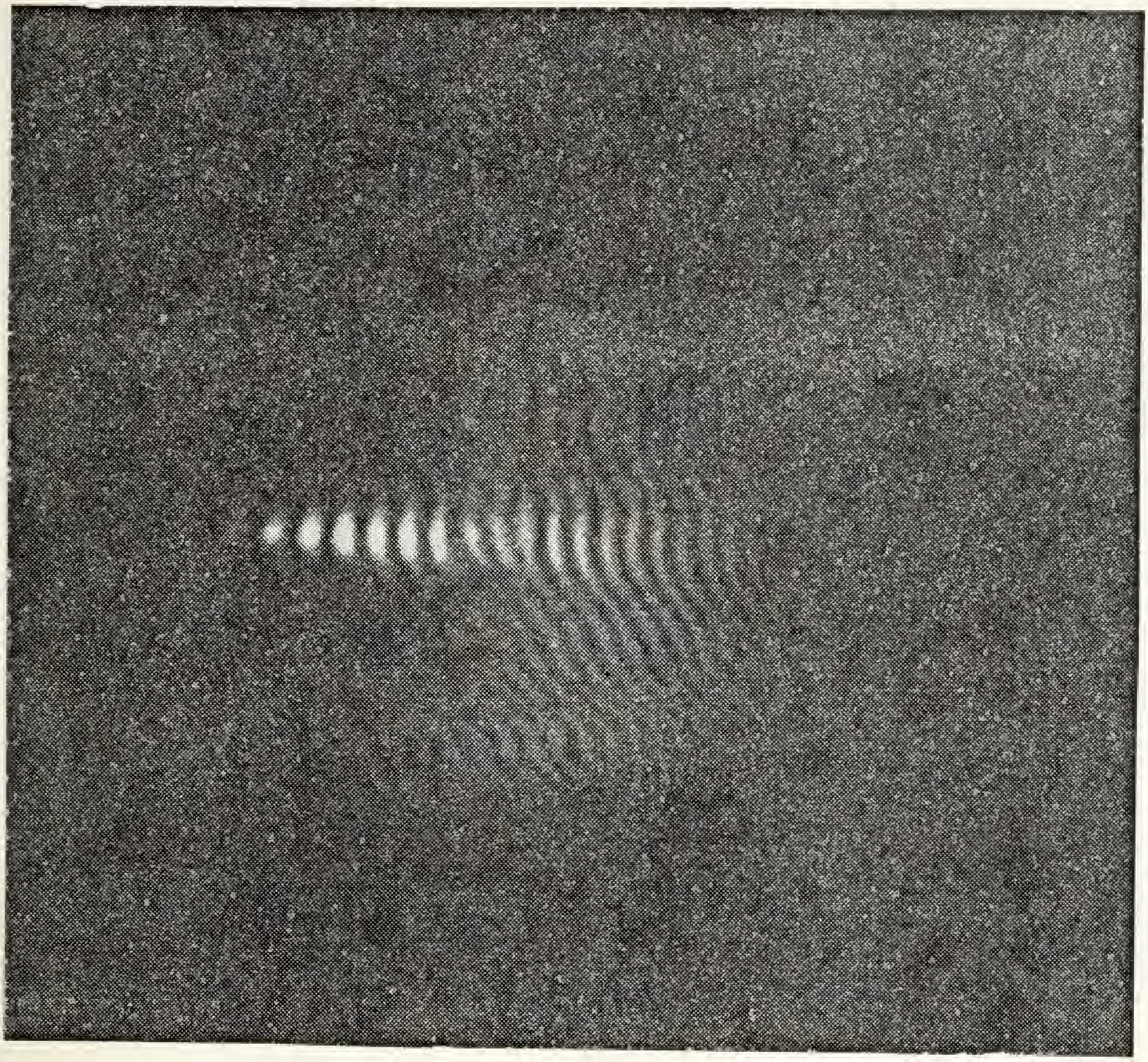


FIGURE 18. Double-Exposure Hologram of Pipe with Nonsymmetric Axial Grooves with 310 psi Internal Pressure.

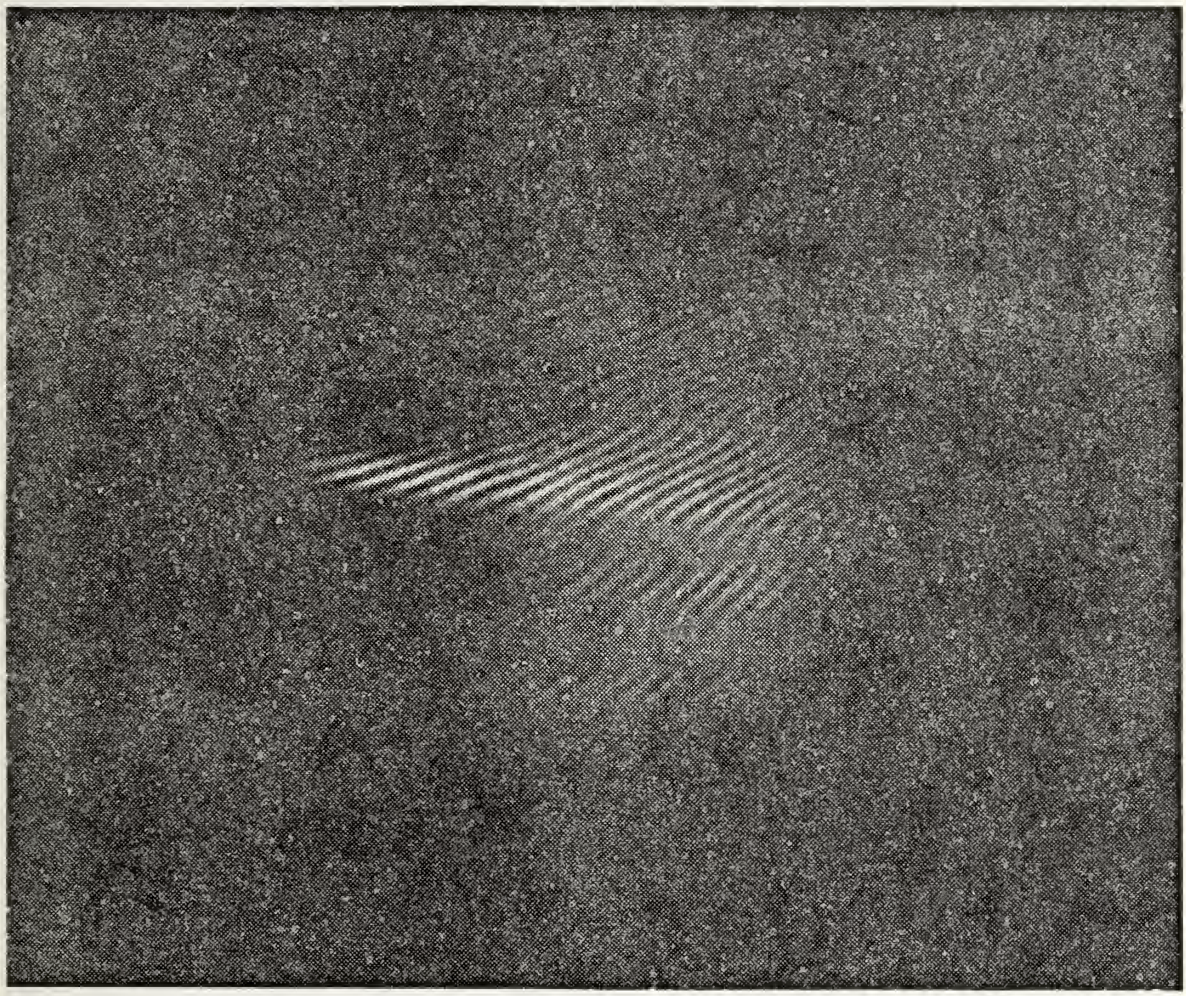


FIGURE 19. Double-Exposure Hologram of Pipe with Nonsymmetric Axial Grooves with 470 psi Internal Pressure.

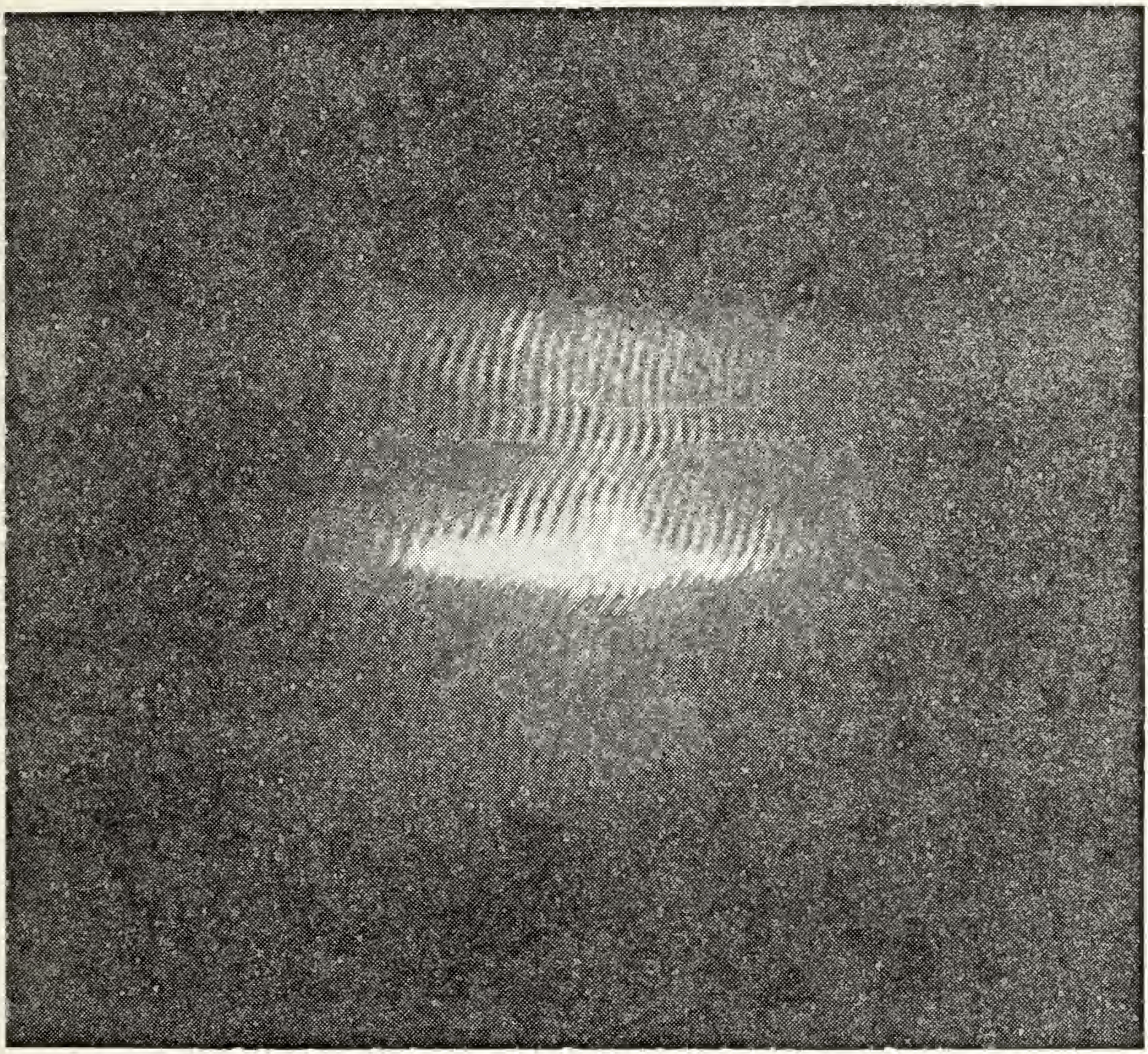


FIGURE 20. Double-Exposure Hologram of Pipe with Symmetric Axial Grooves with 340 psi Internal Pressure.

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